

EL 169835149

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

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**BACKSCATTER COMMUNICATION SYSTEMS,
INTERROGATORS, METHODS OF COMMUNICATING IN A
BACKSCATTER SYSTEM, AND BACKSCATTER
COMMUNICATION METHODS**

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ATTORNEY'S DOCKET NO. MI40-143

1 **BACKSCATTER COMMUNICATION SYSTEMS, INTERROGATORS,**
2 **METHODS OF COMMUNICATING IN A BACKSCATTER SYSTEM,**
3 **AND BACKSCATTER COMMUNICATION METHODS**

4 **TECHNICAL FIELD**

5 The present invention relates to backscatter communication systems,
6 interrogators, methods of communicating in a backscatter system, and
7 backscatter communication methods.

8 **BACKGROUND OF THE INVENTION**

9 Electronic identification systems typically comprise two devices
10 which are configured to communicate with one another. Preferred
11 configurations of the electronic identification systems are operable to
12 provide such communications via a wireless medium.

13 One such configuration is described in U.S. Patent Application
14 Serial Number 08/705,043, filed August 29, 1996, assigned to the
15 assignee of the present application, and incorporated herein by
16 reference. This application discloses the use of a radio frequency (RF)
17 communication system including communication devices. The disclosed
18 communication devices include an interrogator and a remote transponder,
19 such as a tag or card.

20 Such communication systems can be used in various applications
21 such as identification applications. The interrogator is configured to
22 output a polling or interrogation signal which may comprise a radio
23 frequency signal including a predefined code. The remote transponders
24 of such a communication system are operable to transmit an

1 identification signal responsive to receiving an appropriate polling or
2 interrogation signal.

3 More specifically, the appropriate transponders are configured to
4 recognize the predefined code. The transponders receiving the code
5 subsequently output a particular identification signal which is associated
6 with the transmitting transponder. Following transmission of the polling
7 signal, the interrogator is configured to receive the identification signals
8 enabling detection of the presence of corresponding transponders.

9 Such communication systems are useable in identification
10 applications such as inventory or other object monitoring. For example,
11 a remote identification device is attached to an object of interest.
12 Responsive to receiving the appropriate polling signal, the identification
13 device is equipped to output an identification signal. Generating the
14 identification signal identifies the presence or location of the
15 identification device and the article or object attached thereto.

16 Some conventional electronic identification systems utilize
17 backscatter communication techniques. More specifically, the interrogator
18 outputs a polling signal followed by a continuous wave (CW) signal.
19 The remote communication devices are configured to modulate the
20 continuous wave signal in backscatter communication configurations. This
21 modulation typically includes selective reflection of the continuous wave
22 signal. The reflected continuous wave signal includes the reply message
23 from the remote devices which is demodulated by the interrogator.
24

1 Certain drawbacks have been identified with the use of backscatter
2 communication techniques. For example, the transmission of the
3 continuous wave signal using the interrogator can desensitize the receiver
4 of the interrogator during reception thereby of reply signals from
5 associated remote devices. In particular, some of the continuous wave
6 signal tends to bleed through to the received reply messages. Such
7 results in degradation of wireless communications.

8 There exists a need to provide a system which provides improved
9 wireless communications without the drawbacks associated with
10 conventional devices.

11 12 SUMMARY OF THE INVENTION

13 The present invention includes backscatter communication systems,
14 interrogators, methods of communicating in a backscatter system, and
15 backscatter communication methods.

16 One aspect of the present invention provides a method of
17 reducing power within a modulated return link continuous wave signal
18 of a coherent backscatter communication system including an interrogator
19 and at least one remote communication device. Exemplary remote
20 communication devices include remote intelligent communication (RIC)
21 devices and radio frequency identification devices (RFID) of electronic
22 identification systems.

23 The interrogator preferably comprises a coherent interrogator
24 configured to provide backscatter communications. More specifically, the

1 interrogator is configured to output a forward link communication and
2 a wireless continuous wave signal using a transmitter. The interrogator
3 is also configured to output a local continuous wave signal to a receiver
4 of the interrogator following transmission of the forward link
5 communication. Provision of the local signal enables coherent operation
6 of the interrogator. The interrogator is operable to receive return link
7 communications from at least one remote communication device
8 responsive to transmission of the forward link wireless communication.

9 In some embodiments, the interrogator includes a receiver operable
10 to reduce the amplitude of a carrier signal of the return link
11 communication. For backscatter communications, the remote
12 communication device is configured to modulate the continuous wave
13 signal providing a carrier component and side band components. The
14 receiver of the interrogator is preferably configured to reduce the
15 amplitude of the carrier component while maintaining the amplitudes of
16 the side band components.

17 A communication method according to one aspect of the present
18 invention provides reduction of the amplitude of the carrier component
19 of the modulated continuous wave signal. This method includes the
20 steps of matching the amplitude of a local continuous wave signal with
21 an amplitude of a modulated continuous wave signal; adjusting the phase
22 of the local continuous wave signal following the matching; and summing
23 the local continuous wave signal and the modulated continuous wave
24 signal following the adjusting. The adjusting the phase preferably

1 comprises searching for a phase adjustment of the local continuous wave
2 signal which provides maximum reduction of the amplitude of the
3 modulated continuous wave signal at the frequency of the wireless
4 continuous wave signal.

5 6 BRIEF DESCRIPTION OF THE DRAWINGS

7 Preferred embodiments of the invention are described below with
8 reference to the following accompanying drawings.

9 Fig. 1 is a block diagram of an exemplary communication system.

10 Fig. 2 is a front view of a wireless remote communication device
11 according to one embodiment of the invention.

12 Fig. 3 is a front view of an employee badge according to another
13 embodiment of the invention.

14 Fig. 4 is a functional block diagram of a transponder included in
15 the remote communication device of Fig. 2.

16 Fig. 5 is a functional block diagram of an interrogator of the
17 communication system.

18 Fig. 6 is a functional block diagram of an RF section of the
19 interrogator.

20 Fig. 7 is a functional block diagram of an adaptive canceler of
21 the RF section.

22 Fig. 8 is a schematic diagram of amplitude detectors and an
23 amplitude adjuster according to one embodiment of the adaptive
24 canceler.

1 Fig. 9 is a graphical illustration of a summed return link
2 communication output from the adaptive canceler.

3 Fig. 10 is a schematic diagram illustrating one configuration of an
4 amplitude detector and a phase adjuster of the adaptive canceler.

5 Fig. 11 is a graphical illustration of a received return link
6 communication.

7 Fig. 12 is a graphical illustration of a summed return link
8 communication.

9 Fig. 13 is a diagrammatic representation of a forward link
10 communication and a return link communication within the
11 communication system.

12 13 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

14 This disclosure of the invention is submitted in furtherance of the
15 constitutional purposes of the U.S. Patent Laws "to promote the
16 progress of science and useful arts" (Article 1, Section 8).

17 Fig. 1 illustrates a wireless communication system 10 embodying
18 the invention. Communication system 10 comprises an electronic
19 identification system in the embodiment described herein. Further, the
20 described communication system 10 is configured for backscatter
21 communications as described in detail below. Other communication
22 protocols are utilized in other embodiments.

23 The depicted communication system 10 includes at least one
24 electronic wireless remote communication device 12 and an

1 interrogator 26. Radio frequency communications can occur intermediate
2 remote communication devices 12 and interrogator 26 for use in
3 identification systems and product monitoring systems as exemplary
4 applications.

5 Devices 12 include radio frequency identification devices (RFID)
6 or remote intelligent communication (RIC) devices in the embodiments
7 described herein. Exemplary devices 12 are disclosed in U.S. Patent
8 Application Serial No. 08/705,043, filed August 29, 1996. Plural wireless
9 remote communication devices 12 typically communicate with
10 interrogator 26 although only one such device 12 is illustrated in Fig. 1.

11 In one embodiment, wireless remote communication device 12
12 comprises a wireless identification device such as the MicroStamp (TM)
13 integrated circuit available from Micron Communications, Inc., 3176 S.
14 Denver Way, Boise, Idaho 83705. Such a remote communication
15 device 12 can be referred to as a tag or card as illustrated and
16 described below.

17 Although multiple communication devices 12 can be employed in
18 communication system 10, there is typically no communication between
19 multiple devices 12. Instead, the multiple communication devices 12
20 communicate with interrogator 26. Multiple communication devices 12
21 can be used in the same field of interrogator 26 (i.e., within the
22 communications range of interrogator 26). Similarly, multiple
23 interrogators 26 can be in proximity to one or more of devices 12.
24

1 The above described system 10 is advantageous over prior art
2 devices that utilize magnetic field effect systems because, with system 10,
3 a greater range can be achieved, and more information can be obtained
4 (instead of just identification information). As a result, such a
5 system 10 can be used, for example, to monitor large warehouse
6 inventories having many unique products needing individual discrimination
7 to determine the presence of particular items within a large lot of
8 tagged products.

9 Remote communication device 12 is configured to interface with
10 interrogator 26 using a wireless medium in one embodiment. More
11 specifically, communications intermediate communication device 12 and
12 interrogator 26 occur via an electromagnetic link, such as an RF link
13 (e.g., at microwave frequencies) in the described embodiment.
14 Interrogator 26 is configured to output forward link wireless
15 communications 27. Further, interrogator 26 is operable to receive reply
16 or return link wireless communications 29 from devices 12 responsive to
17 the outputting of forward link communication 27. In accordance with
18 the above, forward link communications and return link communications
19 comprise wireless signals, such as radio frequency signals, in the
20 described embodiment. Other forms of electromagnetic communication,
21 such as infrared, acoustic, etc. are possible.

22 Interrogator unit 26 includes a plurality of antennas X1, R1, as
23 well as transmitting and receiving circuitry, similar to that implemented
24 in devices 12. Antenna X1 comprises a transmit antenna and

1 antenna R1 comprises a receive antenna individually connected to
2 interrogator 26.

3 In operation, interrogator 26 transmits the interrogation command
4 or forward link communication signal 27 via antenna X1.
5 Communication device 12 is operable to receive the incoming forward
6 link signal. Upon receiving signal 27, communication device 12 is
7 operable to respond by communicating the responsive reply or return
8 link communication signal 29. Communications of system 10 are
9 described in greater detail below.

10 In one embodiment, responsive signal 29 is encoded with
11 information that uniquely identifies, or labels the particular
12 device 12 that is transmitting, so as to identify any object, animal, or
13 person with which communication device 12 is associated.

14 More specifically, remote device 12 is configured to output an
15 identification signal within reply link communication 29 responsive to
16 receiving forward link wireless communication 27. Interrogator 26 is
17 configured to receive and recognize the identification signal within the
18 return or reply link communication 29. The identification signal can be
19 utilized to identify the particular transmitting communication device 12.

20 Referring to Fig. 2, one embodiment of remote communication
21 device 12 is illustrated. The depicted communication device 12 includes
22 a transponder 16 having a receiver and a transmitter as described
23 below. Communication device 12 further includes a power source 18
24 connected to transponder 16 to supply operational power to

1 transponder 16. In the illustrated embodiment, transponder 16 is in the
2 form of an integrated circuit 19. However, in alternative embodiments,
3 all of the circuitry of transponder 16 is not necessarily all included in
4 integrated circuit 19.

5 Power source 18 is a thin film battery in the illustrated
6 embodiment, however, in alternative embodiments, other forms of power
7 sources can be employed. If the power source 18 is a battery, the
8 battery can take any suitable form. Preferably, the battery type will be
9 selected depending on weight, size, and life requirements for a particular
10 application. In one embodiment, battery 18 is a thin profile button-type
11 cell forming a small, thin energy cell more commonly utilized in watches
12 and small electronic devices requiring a thin profile. A conventional
13 button-type cell has a pair of electrodes, an anode formed by one face
14 and a cathode formed by an opposite face. In an alternative
15 embodiment, the battery comprises a series connected pair of button
16 type cells.

17 Communication device 12 further includes at least one antenna
18 connected to transponder 16 for wireless transmission and reception.
19 In the illustrated embodiment, communication device 12 includes at least
20 one receive antenna 44 connected to transponder 16 for radio frequency
21 reception by transponder 16, and at least one transmit antenna 46
22 connected to transponder 16 for radio frequency transmission by
23 transponder 16. The described receive antenna 44 comprises a loop
24 antenna and the transmit antenna 46 comprises a dipole antenna.

1 Communication device 12 can be included in any appropriate
2 housing or packaging. Fig. 2 shows but one example of a housing in
3 the form of a miniature housing 11 encasing device 12 to define a tag
4 which can be supported by an object (e.g., hung from an object, affixed
5 to an object, etc.).

6 Referring to Fig. 3, an alternative housing is illustrated. Fig. 3
7 shows a housing in the form of a card 13. Card 13 preferably
8 comprises plastic or other suitable material. Plastic card 13 houses
9 communication device 12 to define an employee identification
10 badge including the communication device 12. In one embodiment, the
11 front face of card 13 has visual identification features such as an
12 employee photograph or a fingerprint in addition to identifying text.

13 Although two particular types of housings have been disclosed, the
14 communication device 12 can be included in any appropriate housing.
15 Communication device 12 is preferably of a small size that lends itself
16 to applications employing small housings, such as cards, miniature tags,
17 etc. Larger housings can also be employed. The communication
18 device 12, provided in any appropriate housing, can be supported from
19 or attached to an object in any desired manner.

20 Fig. 4 is a high level circuit schematic of transponder 16 utilized
21 in the devices of Figs. 1-3. In the embodiment shown in Fig. 4,
22 transponder 16 is implemented within monolithic integrated circuit 19.
23 In the illustrated embodiment, integrated circuit 19 comprises a single
24 die, having a size of 209 x 116 mils², including a receiver 30,

1 transmitter 32, microcontroller or microprocessor 34, a wake up timer
2 and logic circuit 36, a clock recovery and data recovery circuit 38, and
3 a bias voltage and current generator 42. Integrated circuit 19
4 preferably comprises a small outline integrated circuit (SOIC) package.
5 Receiver 30 and transmitter 32 comprise wireless communication circuitry
6 configured to communicate wireless signals.

7 In one embodiment, communication devices 12 switch between a
8 "sleep" mode of operation, and higher power modes to conserve energy
9 and extend battery life during periods of time where no interrogation
10 signal 27 is received by devices 12, using the wake up timer and logic
11 circuitry 36.

12 In one embodiment, a spread spectrum processing circuit 40 is
13 included in transponder 16. In this embodiment, signals transmitted and
14 received by interrogator 26 and signals transmitted and received by
15 communication device 12 are modulated spread spectrum signals. Many
16 modulation techniques minimize required transmission bandwidth.
17 However, the spread spectrum modulation techniques employed in the
18 illustrated embodiment require a transmission bandwidth that is up to
19 several orders of magnitude greater than the minimum required signal
20 bandwidth. Although spread spectrum modulation techniques are
21 bandwidth inefficient in single user applications, they are advantageous
22 where there are multiple users, as is the case with the preferred radio
23 frequency identification communication system 10 of the present
24 invention.

1 The spread spectrum modulation technique of the illustrated
2 embodiment is advantageous because the interrogator signal can be
3 distinguished from other signals (e.g., radar, microwave ovens, etc.)
4 operating at the same frequency. The spread spectrum signals
5 transmitted by communication device 12 and interrogator 26 are pseudo
6 random and have noise-like properties when compared with the digital
7 command or reply. The illustrated embodiment employs direct sequence
8 spread spectrum (DSSS) modulation.

9 In operation, interrogator 26 sends out a command that is spread
10 around a certain center frequency (e.g, 2.44 GHz). After the
11 interrogator transmits the command, and is expecting a response, the
12 interrogator switches to a continuous wave (CW) mode for backscatter
13 communications. In the continuous wave mode, interrogator 26 does not
14 transmit any information. Instead, the interrogator just transmits a
15 radio frequency continuous wave signal. In the described embodiment,
16 the continuous wave signal comprises a radio frequency 2.44 GHz carrier
17 signal. In other words, the continuous wave signal transmitted by
18 interrogator 26 is not modulated. After communication device 12
19 receives the forward link communication from interrogator 26,
20 communication device 12 processes the command.

21 If communication device 12 is operating in a backscatter mode,
22 device 12 modulates the continuous wave signal providing a modulated
23 continuous wave signal to communicate return link communication 29
24 responsive to reception of forward communication signal 27.

1 Communication device 12 may modulate the continuous wave signal
2 according to a subcarrier or modulation signal. Modulation by
3 device 12 comprises selective reflection of the continuous wave signal.
4 In particular, device 12 alternately reflects or does not reflect the
5 continuous wave signal from the interrogator to send its reply. For
6 example, in the illustrated embodiment, two halves of a dipole antenna
7 are either shorted together or isolated from each other to send a reply.
8 Alternatively, communication device 12 can communicate in an active
9 mode.

10 The modulated continuous wave signal communicated from
11 device 12 comprises a carrier component and plural side band
12 components about the carrier component resulting from the modulation.
13 More specifically, the modulated continuous wave signal output from
14 device 12 includes a radio frequency continuous wave signal having a
15 first frequency (2.44 GHz), also referred to as a carrier component, and
16 a subcarrier modulation signal having a different frequency (e.g., 600
17 kHz) and which provides the side band components. In particular, the
18 side band components are at +/- 600 kHz of the carrier component.
19 The carrier and side band components are illustrated in Fig. 11 and
20 Fig. 12.

21 In one embodiment, the clock for transponder 16 is extracted
22 from the incoming message itself by clock recovery and data recovery
23 circuitry 38. This clock is recovered from the incoming message, and
24 used for timing for microcontroller 34 and all the other clock circuitry

1 on the chip, and also for deriving the transmitter carrier or the
2 subcarrier, depending on whether the transmitter is operating in active
3 mode or backscatter mode.

4 In addition to recovering a clock, the clock recovery and data
5 recovery circuit 38 also performs data recovery on valid incoming
6 signals. The valid spread spectrum incoming signal is passed through
7 the spread spectrum processing circuit 40, and the spread spectrum
8 processing circuit 40 extracts the actual ones and zeros of data from
9 the incoming signal. More particularly, the spread spectrum processing
10 circuit 40 takes chips from the spread spectrum signal, and reduces
11 individual thirty-one chip sections down to a bit of one or zero, which
12 is passed to microcontroller 34.

13 Microcontroller 34 includes a serial processor, or I/O facility that
14 receives the bits from spread spectrum processing circuit 40. The
15 microcontroller 34 performs further error correction. More particularly,
16 a modified hamming code is employed, where each eight bits of data
17 is accompanied by five check bits used by the microcontroller 34 for
18 error correction. Microcontroller 34 further includes a memory, and
19 after performing the data correction, microcontroller 34 stores bytes of
20 the data bits in memory. These bytes contain a command sent by the
21 interrogator 26. Microcontroller 34 is configured to respond to the
22 command.

23 For example, interrogator 26 may send a command requesting that
24 any communication device 12 in the field respond with the device's

1 identification number. Status information can also be returned to
2 interrogator 26 from communication devices 12.

3 Communications from interrogator 26 (i.e., forward link
4 communications) and devices 12 (i.e., return link communications) have
5 a similar format. Exemplary communications are discussed below with
6 reference to Fig. 13. More particularly, the forward and reply
7 communications individually include a calibration period, preamble, and
8 Barker or start code which are followed by actual data in the described
9 embodiment. The incoming forward link message and outgoing reply
10 preferably also include a check sum or redundancy code so that
11 transponder 16 or interrogator 26 can confirm receipt of the entire
12 message or reply.

13 Communication devices 12 typically include an identification
14 sequence identifying the particular tag or device 12 sending the reply.
15 Such implements the identification operations of communication
16 system 10.

17 After sending a command, interrogator 26 sends the unmodulated
18 continuous wave signal. Return link data can be Differential Phase
19 Shift Key (DPSK) modulated onto the continuous wave signal using a
20 square wave subcarrier with a frequency of approximately 600 kHz
21 (e.g., 596.1 kHz in one embodiment). A data 0 corresponds to one
22 phase and data 1 corresponds to another, shifted 180 degrees from the
23 first phase.
24

1 The subcarrier or modulation signal is used to modulate antenna
2 impedance of transponder 16 and generate the modulated continuous
3 wave signal. For a simple dipole, a switch between the two halves of
4 the dipole antenna is opened and closed. When the switch is closed,
5 the antenna becomes the electrical equivalent of a single half-wavelength
6 antenna that reflects a portion of the power being transmitted by the
7 interrogator. When the switch is open, the antenna becomes the
8 electrical equivalent of two quarter-wavelength antennas that reflect very
9 little of the power transmitted by the interrogator. In one embodiment,
10 the dipole antenna is a printed microstrip half wavelength dipole
11 antenna.

12 Referring to Fig. 5, one embodiment of interrogator 26 is
13 illustrated. The depicted interrogator 26 includes a microcontroller 70,
14 a field programmable gate array (FPGA) 72, and RF section 74. In
15 the depicted embodiment, microcontroller 70 comprises a MC68340
16 microcontroller available from Motorola, Inc. FPGA 72 comprises
17 an XC4028 device available from Xilinx, Inc. Further details of
18 components 70, 72, and 74 are described below.

19 RAM 76, EPROM 78 and flash memory 80 are coupled with
20 microcontroller 70 in the depicted embodiment. Microcontroller 70 is
21 configured to access an applications program for controlling the
22 interrogator 26 and interpreting responses from devices 12. The
23 processor of microcontroller 70 is configured to control communication
24 operations with remote communication devices 12 during normal modes

1 of operation. The applications program can also include a library of
2 radio frequency identification device applications or functions. These
3 functions effect radio frequency communications between interrogator 26
4 and communication device 12.

5 RF section 74 is configured to handle wireless (e.g., radio
6 frequency) communications with remote communication devices 12.
7 DPSK modulation techniques can be utilized for communications
8 intermediate devices 12 and interrogator 26. RF section 74 can include
9 downconversion circuitry for generating in-phase (I) and quadrature (Q)
10 signals which contain the DPSK modulated subcarrier for application to
11 FPGA 72 during return link communications.

12 Plural antennas, including a transmit antenna X1 and a receive
13 antenna R1 are coupled with RF section 74 for wireless RF
14 communications. Plural RF transmit (TX) ports and RF receive (RX)
15 ports (not shown) are coupled with RF section 74 in a preferred
16 embodiment. Provision of plural TX ports and RX ports enables
17 interrogator 26 to minimize the effects of multipath when communicating
18 with plural remote communication devices 12.

19 Analog to digital converters 82, 84 provide received analog RF
20 signals into a digital format for application to FPGA 72. In particular,
21 analog to digital converters 82, 84 are implemented intermediate
22 FPGA 72 and RF section 74 for both in-phase (I) and quadrature (Q)
23 communication lines. An additional connection 85 is provided
24 intermediate FPGA 72 and RF section 74. Digital signals output from

1 FPGA 72 via connection 85 are converted to RF signals by RF
2 section 74. Connection 85 can be utilized to transmit phase lock loop
3 (PLL) information, antenna diversity selection information and other
4 necessary communication information. During forward link
5 communications, FPGA 72 is configured to format communication packets
6 received from microcontroller 70 into a proper format for application
7 to RF section 74 for communication.

8 FPGA 72 is configured to demodulate return link communications
9 received from remote communication devices 12 via RF section 74.
10 FPGA 72 is configured in the described embodiment to perform I
11 and Q combination operations during receive operations. The described
12 FPGA 74 further includes delay and multiplication circuitry to remove
13 the subcarrier. FPGA 74 can also include bit synchronization circuitry
14 and lock detection circuitry. Data, clock and lock detection signals
15 generated within FPGA 74 are applied to microcontroller 70 for
16 processing in the described embodiment.

17 Microcontroller 70 is configured to control operations of
18 interrogator 26 including outputting of forward link communications and
19 receiving reply link communications. EPROM 78 is configured to store
20 original code and settings selected for the particular application of
21 communication system 10. Flash memory 80 is configured to receive
22 software code updates which may be forwarded to interrogator 26.

23 RAM device 76 is configured to store data during operations of
24 communication system 10. Such data can include information regarding

1 communications with associated remote communication devices 12 and
2 status information of interrogator 26 during normal modes of operation.

3 Referring to Fig. 6, an exemplary embodiment of RF circuitry 74
4 is illustrated. The depicted RF circuitry 74 includes a transmit path 86
5 and a receive path 87. In the depicted embodiment, RF section 74
6 includes a transmitter 90, coupler 91 and power amplifier 92 within
7 transmit data path 86. Receive path 87 includes a receiver 95
8 comprising processing circuitry 96 and an adaptive canceler 97 in the
9 depicted embodiment.

10 Communication paths 86, 87 are coupled with respective
11 antennas X1 and R1. Transmit path 86 is additionally coupled with
12 FPGA 72 via connection 85. Receive path 87 is coupled with analog-
13 to-digital converters 82, 84 via the I, and Q connection lines.

14 During communication operations, transmitter 90 is configured to
15 output a radio frequency wireless forward link communication 27 and
16 a radio frequency wireless continuous wave signal using coupler 91 and
17 antenna X1. Further, transmitter 90 is also configured to output a
18 local continuous wave signal using coupler 91. Transmitter 90 is
19 preferably configured to simultaneously output the wireless continuous
20 wave signal using antenna X1, and the local continuous wave signal
21 using coupler 91. The wireless continuous wave signal transmitted via
22 antenna X1 and the local continuous wave signal provided to
23 receiver 95 via coupler 91 have a common frequency (e.g., 2.44 GHz
24 in the described embodiment).

Receiver 95 is operable to receive the return link communications 29 from at least one remote communication device 12 using antenna R1. As described in detail below, adaptive canceler 97 of receiver 95 is configured to receive the local continuous wave signal from coupler 91. Provision of the local signal provides a coherent backscatter interrogator 26 including a coherent transmitter 90 and receiver 95.

As previously described, return link communication 29 comprises a modulated continuous wave signal in the described embodiment. The modulated signal comprises a carrier signal located at the frequency of the wireless continuous wave signal (e.g., 2.44 GHz), and side bands located at +/- 600 kHz about the frequency of the carrier signal. In the described embodiment, receiver 95 is configured to reduce the power or amplitude of the return link communication. More specifically, receiver 95 is configured to reduce the power or amplitude of the carrier signal of the return link communication.

In one embodiment, receiver 95 is operable to reduce the amplitude of the return link communication comprising the modulated continuous wave signal using the local continuous wave signal. More specifically, receiver 95 is configured to reduce the amplitude of the return link communications received by antenna R1 at the common frequency of the continuous wave signals in the described embodiment.

As described in detail below, receiver 95 is configured to receive the local continuous wave signal from coupler 91 and adjust the

1 amplitude and phase of the local continuous wave signal. Such
2 adjustment provides an adjusted continuous wave signal. In particular,
3 the amplitude of the local continuous wave signal is adjusted responsive
4 to the amplitude of the modulated continuous wave signal. Preferably,
5 the amplitude of the local continuous wave signal is adjusted to match
6 the amplitude of the received return link communication. The
7 amplitude of the local continuous wave signal is adjusted before
8 adjustment of the phase of the local continuous wave signal in the
9 described embodiment. Following amplitude and phase adjustment,
10 receiver 95 is configured to sum the adjusted continuous wave signal
11 with the modulated continuous wave signal. Thereafter, the summed
12 return link communication having a reduced amplitude at the frequency
13 of the wireless continuous wave signal is applied to processing
14 circuitry 96.

15 Referring to Fig. 7, one embodiment of adaptive canceler 97 is
16 illustrated. Adaptive canceler 97 is configured to reduce the amplitude
17 of return link communications 29. More specifically, during backscatter
18 communications, receive path 87 is susceptible to bleed through of the
19 wireless continuous wave signal transmitted via antenna X1. More
20 specifically, the wireless continuous wave signal communicated via
21 transmit antenna X1 can saturate the front end of receiver 95. This
22 leakage can desensitize receiver 95 and reduce the quality of wireless
23 communications of interrogator 26 with remote communication
24 devices 12.

1 Adaptive canceler 97 utilizes the local continuous wave signal
2 received from transmitter 90 and coupler 91 to reduce the amplitude
3 of the return link communication received by antenna R1 at the
4 frequency of the wireless continuous wave signal transmitted via
5 antenna X1.

6 As previously described, transmitter 90 is configured to output
7 local and wireless continuous wave signals using coupler 91. Initially,
8 the local continuous wave signal is applied to a variable attenuator 105
9 within adaptive canceler 97. In the described embodiment, variable
10 attenuator 105 comprises a voltage controlled attenuator. Variable
11 attenuator 105 is configured to adjust the amplitude of the local
12 continuous wave signal responsive to an external control signal discussed
13 below.

14 Variable attenuator 105 outputs an amplitude adjusted local
15 continuous wave signal. The amplitude adjusted local continuous wave
16 signal is applied to a phase shifter 106. Phase shifter 106 preferably
17 comprises a 360° phase shifter configured to provide an appropriate
18 phase shift of the amplitude adjusted local continuous wave signal.
19 Phase shifter 106 outputs an amplitude and phase adjusted local
20 continuous wave signal which is also referred to as the adjusted
21 continuous wave signal. Phase shifter 106 is controllable via an external
22 control signal described below.

23 The amplitude and phase adjusted local continuous wave signal
24 output from phase shifter 106 is supplied to a power divider 107.

1 Power divider 107 operates to apply the signal to a detector 108 and
2 coupler 109. Detector 108 is operable to measure the amplitude of the
3 adjusted local signal and apply an output signal to an amplitude
4 adjuster 110.

5 Return link communication 29 received via antenna R1 is applied
6 to a coupler 114. Coupler 114 applies the received return link
7 communication 29 to coupler 109 and an amplitude detector 115.
8 Detector 115 is configured to measure the amplitude of the received
9 return link communication 29.

10 Referring to Fig. 8, exemplary embodiments of amplitude
11 adjuster 110 and detectors 108, 115 are illustrated. Detectors 108, 115
12 individually comprise discrete components including diodes, resistors and
13 capacitors. Detectors 108, 115 are configured to measure the amplitude
14 of the respective adjusted continuous wave signal and the modulated
15 continuous wave signal.

16 The measured amplitude values are applied to amplitude
17 adjuster 110 which comprises a feedback amplifier configuration in the
18 depicted embodiment. The illustrated analog implementation of
19 amplitude adjuster 110 is configured to drive variable attenuator 105 to
20 equalize the amplitudes of the adjusted continuous wave signal and the
21 modulated continuous wave signal. Amplitude adjuster 110 is configured
22 to compare the amplitudes of the adjusted continuous wave signal and
23 the received return link communication comprising the modulated
24 continuous wave signal. Thereafter, amplitude adjuster 110 is operable

1 to output a control signal to variable attenuator 105 to match the
2 amplitudes of the respective signals. Other configurations of amplitude
3 adjuster 110 are possible.

4 Referring again to Fig. 7, coupler 109 is configured to sum the
5 adjusted continuous wave signal and the received modulated continuous
6 wave signal to reduce the amplitude of the modulated continuous wave
7 signal. The summed continuous wave signal or return link
8 communication is applied to a coupler 118. Coupler 118 is configured
9 to apply the summed signal to low noise amplifier (LNA) 119 and
10 amplitude detector 120. Amplitude detector 120 is configured to
11 measure the amplitude of the summed signal and apply an output signal
12 to a phase adjuster 121.

13 Phase adjuster 121 is controllable responsive to amplitude
14 adjuster 110. Once amplitude adjuster 110 and variable attenuator 105
15 have matched the amplitudes of the adjusted continuous wave signal and
16 the received return link communication, amplitude adjuster indicates the
17 match to phase adjuster 121 via a connection 122. Thereafter, phase
18 adjuster 121 operates to select an appropriate phase shift of the
19 amplitude adjusted local continuous wave signal.

20 In the described embodiment, phase adjuster 121 is configured to
21 search across 360° of possible phase adjustments to detect a phase
22 adjustment of the local continuous wave signal which provides maximum
23 reduction of amplitude of the received modulated continuous wave signal
24 at the continuous wave signal frequency. In particular, adaptive

canceler 97 adjusts the phase of the local continuous wave signal following matching of amplitudes of the local continuous wave signal and the received modulated continuous wave signal as indicated via connection 122.

Referring to Fig. 9, a graphical illustration of the amplitude of the summed return link communication, represented by reference numeral 136, is illustrated with respect to corresponding plural phase adjustments of the local continuous wave signal. In the depicted illustration, it is shown that a local minimum value 130 corresponds to approximately 150° . For such a situation following searching of 360° , phase adjuster 121 will apply an appropriate control signal to phase shifter 106 to implement the desired phase shift of approximately 150° to minimize the amplitude of the bleed through of the wireless continuous wave signal within the received return link communication.

Referring again to Fig. 7, the summed return link communication is applied to low noise amplifier 119 and processing circuitry 96. Phase adjuster 121 is operable to continuously monitor the amplitude of the summed return link communication and provide appropriate adjustments using control signals applied to phase shifter 106 to minimize the amplitude of the continuous wave signal within the summed return link communication applied to LNA 119.

Referring to Fig. 10, exemplary embodiments of amplitude detector 120 and phase adjuster 121 are illustrated. Amplitude

1 detector 120 includes discrete components comprising a diode, resistor
2 and capacitor.

3 Phase adjuster 121 comprises an analog-to-digital converter 124,
4 processor 125 and digital-to-analog converter 126. Processor 125 can be
5 configured to execute appropriate algorithms to implement sequential
6 phase shifts of the local signal from 0° to 360° . The incremental step
7 sizes can be adjusted. Therefore, processor 125 can compare the
8 amplitudes of the summed return link communication signal responsive
9 to various phase adjustments implemented by phase shifter 106.
10 Following selection of an appropriate phase shift, phase adjuster 121 can
11 continue to monitor the amplitude of the summed return link
12 communication and update the phase shift as necessary to maintain
13 maximum reduction of the continuous wave signal within the return link
14 communication during communications. The depicted configurations of
15 detector 120 and phase adjuster 121 are illustrative and other
16 configurations can be utilized.

17 Referring to Fig. 11 and Fig. 12, the received return link
18 communication applied to adaptive canceler 97 and the summed return
19 link communication output from adaptive canceler 97 are illustrated.
20 The received return link communication comprising the modulated
21 continuous wave signal is illustrated as signal 132 in Fig. 11. The
22 summed return link communication is represented by signal 136 of
23 Fig. 12.
24

Signal 132 comprises a carrier component 133 and side band components 134. In the described embodiment, carrier 133 is centered at a frequency of 2.44 GHz and subcarrier side band components 134 are depicted at locations ± 600 kHz of the carrier component 133. Signal 136 similarly comprises a carrier component 137 and side band components 138. Signal 136 includes carrier component 137 at a frequency of 2.44 GHz and side band components 138 at locations ± 600 kHz of the carrier component 137.

As illustrated, the output summed return link communication signal 136 has a carrier component 137 having a reduced amplitude compared with the carrier component 133 of the received return link communication signal 132. Preferably, the amplitude of side band components 138 of summed return link communication signal 136 are maintained during the reduction of amplitude of the carrier component 137 as illustrated in Fig. 11 and Fig. 12.

In the depicted illustrations of Fig. 11 and Fig. 12, carrier component 137 of signal 136 is approximately 20 dBm less than carrier component 133 of received return link communication 132. Such indicates the reduction of amplitude of the return link communication signal at the frequency of the wireless continuous wave signal (e.g., 2.44 GHz) utilizing adaptive canceler 97.

Referring to Fig. 13, a diagrammatic illustration of forward link communication 27 and return link communication 29 is shown. Initially, forward link communication 27 is communicated using transmit

1 antenna X1 of interrogator 26. Following an intermediate delay or
2 guard band, return link communication 29 corresponding to remote
3 communication device 12 is communicated.

4 Individual return link communications 29 include a calibration
5 period 140 followed by a preamble 141 and actual data 142. Matching
6 of amplitudes of the local continuous wave signal and the received
7 return link communication and cycling through phases from 0 to 360°
8 utilizing phase adjuster 121 and phase shifter 106 preferably occurs
9 during calibration period 140. The minimum level 130 within the
10 summed return link communication signal is preferably determined during
11 calibration period 140.

12 Preamble 141 can be utilized to synchronize the processing
13 circuitry 96 of receiver 95 with the actual return link communication 29
14 being received. Thereafter, data 142 communicated from remote
15 communication device 12 is received. Adaptive canceler 97 is configured
16 to make adjustments as necessary to the amplitude and phase of the
17 local continuous signal during preamble period 141 and data period 142
18 to maintain maximum reduction of the continuous wave signal within the
19 received return link communication 29.

20 In compliance with the statute, the invention has been described
21 in language more or less specific as to structural and methodical
22 features. It is to be understood, however, that the invention is not
23 limited to the specific features shown and described, since the means
24 herein disclosed comprise preferred forms of putting the invention into

1 effect. The invention is, therefore, claimed in any of its forms or
2 modifications within the proper scope of the appended claims
3 appropriately interpreted in accordance with the doctrine of equivalents.
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